

Full Length Research Paper

Performance of self-compacting concrete made with hydraulic lime as filler

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Concrete is a very popular artificial material on earth and it is one of the most used construction material in building technology. Self-Compacting Concrete (SCC) is a highly workable concrete designed such that it is able to be placed in any formwork without external compaction or vibration. It consolidates and fills voids by the help of its self-weight even in the presence of very dense reinforcement. This paper presents the design of a self-consolidating concrete mix with lime as filler which can be used in day to day normal concrete applications. Twenty-six mixes were prepared with different packing factors for aggregates, cement and lime contents and superplasticizer dosage to get optimum proportions for SCC. Traditional Vibrated Concrete (TVC) mixes of normal strength were also designed. Workability tests were carried out on both concrete types which included testing the flow characteristics of SCC and the slump for TVC. Compressive and tensile strength tests were carried out on cubes and cylinders made from both mixes. Results from the experiment showed that the amount of cement normally required to make the SCC was replaced by lime by about 30% to obtain a normal strength of about 30 MPa. It was also observed that the tensile strength of SCC was slightly higher than that of TVC.

Key words: Self-compacting concrete, hydraulic lime, compressive strength, split tensile strength.

INTRODUCTION

Concrete is the second most utilized substance in the world after water and is the most widely used construction material with an annual global production of about 10 billion tonnes. It is preferred in most structures because of its unique properties such as durability and high compressive strength. Traditional vibrated concrete is most commonly used but it has limitations such as difficulty to place in areas of congested reinforcement,

complex formwork and lack of compacting assurance as the vibrator may not reach all the areas of the formwork. Vibration is what pushes the concrete to confinement. It gets rid of entrapped air in concrete after it has been placed. The presence of this air increases permeability and hence jeopardizes concrete durability. The air voids also reduce contact between concrete and reinforcement and hence reduce bond and strength expected. The high

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Table 1. Mix proportion for traditional vibrated concrete.

Cement (kg/m ³)	Sand (kg/m ³)	Coarse Agg. (kg/m ³)	Water (kg/m ³)	W/P
340	655	1170	190	0.55

flow ability, passing ability and stability of self-compacting concrete gets rid of these inconveniences and enhances productivity in construction.

Traditional self-compacting concrete requires huge amounts of binder content in order to achieve these characteristics and also exerts high lateral pressure on formwork. It is also prone to creep, shrinkage and cracking due to a high heat of hydration (Ghezal and Assaf, 2014). Partially replacing cement with a filler such as hydraulic lime reduces the heat of hydration and also the material cost of the SCC. Research has been carried on Process and Application of Self-Compacting Concrete (Zekong and Mao, 2015; Yasser et al., 2015).

Self-compacting concrete dates back to the late 1980s when the Japan construction industry experienced a decline in the availability of skilled labour and problems of defective workmanship in concrete structures. Hence, proper construction on site could not be ensured (Ouchi et al., 1996). Prof Hitoshi Okamura immediately started research to develop self-compacting concrete in 1986 at the University of Tokyo (Ozawa et al., 1989). The first prototype of Self-Compacting Concrete (SCC) was produced in 1988, using locally available materials in the Japanese market (Okamura and Ouchi, 2003).

Self-compacting concrete is made with mineral and chemical admixtures and additives which are responsible for its characteristic properties which include its filling ability, passing ability and resistance to segregation. The yield stress is the amount of stress needed to start or maintain flow while the plastic viscosity is its resistance to flow once the yield stress has been exceeded. The yield stress must be near zero to ensure that the SCC can flow and consolidate under its own weight. The plastic viscosity also should not be too low, as it could result to poor stability (Koehler and Fowler, 2007). The low yield strength is achieved using an adequate amount of super plasticizer.

MATERIALS and METHODS

The following materials were used in this research.

Cement

The cement used in this experimental work is Rhino Power plus 42.5 Ordinary Portland cement having a specific gravity of 3.15.

Fine aggregate

Locally available Meru sand passed through the 4.75 mm sieve was

used as fine aggregate. After testing, it was shown to have a specific gravity of 2.7, a fineness modulus of 2.55, a water absorption capacity of 0.1% and moisture content of 0.75%. The loose and rodded bulk density values are 1375 and 1649 kg/m³, respectively.

Coarse aggregate

The coarse aggregate used in this experimental work were crushed stones from Mlolongo with a maximum size of 20 mm, specific gravity of 2.6, fineness modulus of 2.7, a water absorption capacity of 2.43% and moisture content of 5.6%. The loose and rodded bulk density values are 1309 and 1415 kg/m³, respectively.

Hydraulic lime

Hydraulic lime used which was in powder form was procured from ARM Cement Limited known as 'Rhino Lime'. It had a specific gravity of 2.4.

Superplasticizer

Two polycarboxylate ether based superplasticisers were used in this experiment: SikaViscocrete 3088 and SikaViscocrete 10. V3088 is a brownish liquid while V10 is a clear liquid. Both have a specific gravity of 1.06.

Water

Clean potable water was used for mixing.

Mix proportion for traditional vibrated concrete

The normal concrete mix (Table 1) was designed according to the Building Research Establishment (BRE) concrete mix design method for a concrete strength of 30 MPa at 28 days. Trial mixes and adjustments were carried out until the required strength and workability was obtained.

Mix proportion for self-compacting concrete

The modified method (Su et al., 2001) was used for the SCC mix design. In this method, the packing factor is first assumed and then the voids between the aggregates are filled with a binding paste consisting of cement and hydraulic lime to get the desired workability, flow properties and strength. The following steps in the (Su et al., 2001) method were then used to calculate the material proportions. Trial mixes were carried out to adjust the optimum packing factor, the optimum superplasticizer dosage, water/powder ratio and cement content required to get a characteristic compressive strength of 30MPa and the required workability.

The initial mix design was carried out at a PF of 1.17, a coarse

Table 2. Mix Proportions with V3088 and max aggregate size 15 mm (Group 1).

Mix ID	PF	C.A. (kg/m ³)	F.A. (kg/m ³)	Cement (kg/m ³)	Lime (kg/m ³)	Water (kg/m ³)	S.P. (%)	W/P ratio
1	1.17	690.2	766.8	107	373.4	186.5	1.8	0.38
2	1.17	684.3	760.2	230.8	224.4	222.5	1.8	0.49
3	1.16	684.3	760.2	230.8	204.1	228.9	1.8	0.53
4	1.16	684.3	760.2	230.8	209	226.7	1.8	0.52
5	1.16	684.3	760.2	230.8	224.6	224.6	1.8	0.51
6	1.18	665.2	801.47	214.3	218.9	218.8	1.6	0.51
7	1.12	631.3	760.7	272.7	225.1	223	1.1	0.45
8	1.12	631.3	760.7	300	178.2	235.9	1.1	0.49
9	1.12	631.3	760.7	300	179.6	237.5	0.8	0.49
10	1.12	631.3	760.7	300	179.1	237	0.9	0.49

PF: Packing factor; CA: coarse aggregate; FA: fine aggregate; SP: superplasticiser; W/P: water/powder ratio.

Table 3. Mix Proportions with V10 and max aggregate size 10 mm (Group 2).

Mix ID	PF	C.A. (kg/m ³)	F.A. (kg/m ³)	Cement (kg/m ³)	Lime (kg/m ³)	Water (kg/m ³)	S.P. (%)	W/P ratio
11	1.12	631	878	300	188	243	1.4	0.5
12	1.12	631	878	300	188	243	1.3	0.5
13	1.12	631	878	300	202	237	1.3	0.47
14	1.12	631	878	300	189	244	1.2	0.5
15	1.12	630	878	300	189	244	1.2	0.5
16	1.12	631	878	300	193	244	1	0.5
17	1.12	630	878	350	156	241	1.4	0.48
18	1.12	630	878	350	162	218	1.4	0.43
19	1.12	630	878	350	145	247	1.3	0.5
20	1.12	630	878	350	157	242	1.3	0.48
21	1.12	630	878	350	162	218	1.3	0.42
22	1.12	630	878	350	162	196	1.3	0.38
23	1.12	630	878	350	149	246	1.2	0.49
24	1.12	630	878	350	162	239	1.2	0.47
25	1.12	630	878	350	207	264	1.18	0.46
26	1.12	630	878	350	200	260	1.18	0.47

aggregate content of 27.8% by volume of concrete and a fine aggregate content of 44.30% by volume of mortar in concrete. The water/powder ratio was 0.38 with a V3088 superplasticizer content of 1.80%.

In order to achieve the required slump and a homogenous mix, the coarse aggregate content was decreased to 25% by volume of concrete. Fine aggregate content was increased to 45% and then reduced to 43% by volume of mortar in concrete. Cement content was gradually increased from 100 to 300 kg/m³ and then kept constant. The superplasticizer content decreased from 1.8% of powder content to 0.9%. The water-powder ratio was varied from 0.38 to 0.49 until an acceptable slump flow was achieved but the desired strength was not obtained. Mix proportions for various trial mixes are shown in Table 3.

In order to obtain the desired strength of 30 MPa, the cement content was increased to 350 kg/m³. Superplasticizer dosage was also varied between 1 and 1.4% with a change in superplasticizer from V3088 to V10.

Tests on fresh concrete

For the traditional vibrated concrete in its fresh state, the slump test was carried out for each batch in order to assess the workability of the concrete. For self-compacting concrete, the following tests in its fresh state were carried out as per EFNARC standards.

Slump flow and T50 tests aimed at assessing the flow ability and flow rate of SCC.

Visual Stability Index (VSI) tests were also carried out on all mixes. It is based on if bleed water is observed at the edges of the spreading concrete and if aggregates pile at the centre. This helped to immediately disqualify most of the mix proportions. Plate 1 shows examples of VSI ranging from highly stable homogenous mixes to unacceptable mixes. Visual Stability Rating Criteria is presented in Table 4.

When a homogenous stable mix with an acceptable slump was



Plate 1. VSI tests ranging from stable to unacceptable.

Table 4. Visual stability rating criteria.

Rating	Criteria
0	No evidence of segregation in the slump flow, no bleeding around the edges or aggregate piled at the centre
1	No aggregate pile at the centre of the slump flow but presence of slight bleed and surface bubbles
2	Slight aggregate pile at the centre and highly noticeable bleeding
3	Evidence of large aggregate pile and lots of bleeding

Table 5. Mix proportion for self-compacting concrete.

Cement (kg/m ³)	Sand (kg/m ³)	Coarse Agg. (kg/m ³)	H Lime (kg/m ³)	Water (kg/m ³)	SP (kg/m ³)	W/P
350	878	630	200	260	6.5	0.50

obtained, the following tests for self-compatibility were carried out to determine the self-compacting characteristics of the fresh concrete mix: the L-box, J-ring, V-funnel and segregation resistance tests. Tests for strength parameters were carried out on cube and cylinder specimens of standard sizes. Three specimens for each mix were tested and the average value was used. The optimal mix proportion for SCC obtained is shown in Table 5.

RESULTS AND DISCUSSION

Workability and compressive strengths

Compressive strength tests were carried out on all SCC mixes and are presented in Table 6. Acceptance criteria for SCC recommended by EFNARC (2002) are presented in Table 7. For the T50 cm test, EFNARC specifications recommend a range of 2 to 5 s while other literature recommend 2 to 10 s. However, T50 is a secondary flow test. A higher T50 value indicates a more viscous mix which is better for concrete in applications with dense

reinforcement while a lower T50 value may be appropriate for concrete in applications with less obstruction.

Split tensile strength

Split tensile strength tests were carried out on 150 mm ×300 mm cylinders for the traditional concrete mix and its comparable mix 26. The cylinders were tested for 7, 14 and 28 day strengths. Split tensile strength for both TVC and SCC increased with age but it is noted that split tensile strength of SCC is more than TVC at all the ages (Table 8).

Conclusion

The slump flow tests, J ring test, V-funnel test and L-box test results were found to be satisfactory showing that the passing ability, filling ability and segregation resistance of

Table 6. Slump flow, visual stability index and compressive strengths.

Mix ID	Slump flow (mm)	Visual stability index	Compressive strengths (MPa)		
			7 days	14 days	28 days
11	737.5	2	14.9	24.5	28.3
12	700.0	2	14.4	23.8	27.5
13	725.0	2	16.0	26.2	30.2
14	550.0	1	15.5	18.6	21.8
15	525.0	2	16.3	17.4	20.4
16	500.0	2	17.5	18.3	21.4
17	700.0	2	17.5	20.8	24.2
18	675.0	2	25.9	29.3	33.6
19	600.0	1	18.4	25.0	28.9
20	575.0	1	17.5	22.4	26.0
21	550.0	2	23.5	26.6	30.6
22	550.0	2	26.2	27.5	31.7
23	650.0	1	19.2	26.9	31.0
24	650.0	1	18.9	26.5	30.6
25	700.0	1	21.7	25.4	31.9
26	700.0	0	23.9	27.2	33.4
Statistical data					
Mean			19.2	24.2	28.2
Variance			14.0	12.4	17.2
Standard deviation			3.7	3.5	4.1

Table 7. Acceptance criteria for SCC recommended by EFNARC and the values obtained from self-compatibility tests.

Property	Units	Range	Value
Slump flow diameter	mm	500-800	700
T50 cm	s	2-5	7
L-box Passing ratio	h_2/h_1	≥ 0.8	0.9
J ring Blocking step, Bj	mm	0 - 10	6.75
J ring Slump flow Sj	mm	500 - 800	675
Jring T50 cm j	s	-	10
V funnel tv	s	6 - 15	13
Segregation resistance Sieved portion	%	5 - 15	2.57

Table 8. Split tensile strength for both TVC and SCC.

Variable	7 days (MPa)	14 days (MPa)	28 days (MPa)
TVC	2.550	2.764	2.872
SCC	2.641	2.978	3.125
Statistical data			
Mean	2.60	2.87	3.00
Variance	0.00	0.01	0.02
Standard deviation	0.05	0.11	0.13

the SCC mix are well within the limits. A good SCC mix for normal strength concrete can be developed for normal day to day concrete applications using hydraulic lime as filler. By using the OPC 42 grade, normal strength SCC of about 30 MPa at 28-days was obtained, keeping the cement content at 350 kg/m³ and the filler content at 200 kg/m³. This is a confirmation that the mixture proportions satisfy the performance requirements for fresh concrete as well as the initially established performance requirement for hardened concrete. SCC mixes can be developed without the use of viscosity modifying agents as done in this study.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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